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Current status and perspectives of renewable energy sources in Poland

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Abstract

Using renewable energy sources is one of the crucial components of the sustainable development, giving rational economic, ecological and social effects. Developed countries notice the necessity of emission reduction from combustion of energy fuels processes and the necessity of seeking alternative energy resources. Support for development of the use of renewable energy sources became a very important objective within the European Union.

In this article the present state and perspectives of using renewable energy sources in Poland are depicted as well as the main tools for promoting their development and utilization.

Keywords: Renewable energy sources; Energy policy; Sustainable development

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1. Introduction

For about two decades now, the term "sustainable development" has characterized the discussions about taking better care of our natural environment, a fairer distribution of prosperity throughout the world, and more human living conditions for all people. Sustainability encompasses not only ecological but also economical and social aspects, which must always be considered collectively and in their interactions. A comprehensive definition for sustainability was worked out for the first time by the Brundtland Commission, adopted by the Rio Conference 1992, and has since been refined, and interpreted. The Brundtland report defines sustainable development as a development that "meets the needs of the present

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without compromising the ability of future generations to meet their own needs''. Energy plays a crucial role in sustainable development [1].

Although there are different opinions about the potential of efficiency enhancements in the energy sector and about the feasibility of CO_2 sequestration, all scenarios conclude that expansion of renewable energies offers the chance to join a path of sustainable energy. Renewable energy is thus the only dependable guarantor for a future energy supply.

Nowadays, in many countries the increase in generating capacity takes place in small units of so-called distributed power industry (distributed generation-DG), and among them in hybrid power (generating) systems (HPS) [2]. They use primary energy conventional sources as well as renewable energy sources (RES), and in many cases produce electricity and heat (CHP). It is very often that definition of DG is connected with definition of renewable energy sources. However, using of RES in many cases includes DG it should not narrow DG down to RES sector because it is important to underline that DG uses also conventional fuels.

2. Definitions of RES and DG and their place in Polish power industry

Polish Energy Law Act [3] defines renewable energy source as a unit which, in the conversion process, uses wind energy, solar energy, geothermal energy, sea wave and tidal energy, river fall energy, biomass energy, energy from landfill biogas and biogas produced in the process of sewage disposal and treatment or decomposition of plants and animal remains. Additionally, the Ministry of Economy ordinance allows using renewable sources together with other fuels (co-firing) [4,5]. Electricity or heat produced from renewable energy shall also include the fraction of energy corresponding to the percentage of fuels used for the production of the electricity or heat.

DG (also called dispersed generation, embedded generation) is a new area where till now it is not an established commonly used terminology. The definition of DG is presented below: small installations or power stations (50–150 MW), connected to a distribution network or located on final consumers side (behind the electricity meter), they often produce electricity using RES or non-conventional fuels and also often in co-generation with heat (CHP technology) [6–9]. An example of DG localization in the power system is illustrated in Fig. 1 [10].

DG uses different kinds of power generation technologies—from traditional, through CHP and RES utilization, and fuel cells as well as energy storage.

The Polish electrical power sector comprises 3 sub-sectors: production, transmission, distribution and turnover of electricity.

The sub-sector of electricity production covers 17 power stations or groups of power stations: including 14 individual power plants (or grouped in power station groups) fuelled by hard coal, 2 independent power stations and a group of 3 system power stations fuelled by brown coal. Moreover, in the production sub-sector there are also 29 CHP stations and groups of CHP stations, 6 individual (or operating as groups) hydropower stations, and about 80 smaller independent local CHP stations, former industrial power plants.

At the end of 2006, the following technical data of the electrical power system were recorded: total electrical installed capacity—35,734 MW, achieved capacity—35,046 MW, maximum annual power demand—23,477 MW. Total electricity generation in 2006 was 161,859 GWh.

By mid-2004 the sub-sector of electrical energy transmission was formed by a sole-stakeholder company of the State Treasury—the Polskie Sieci Elektroenergetyczne S.A. (PSE SA, Polish Power Grid Co.), which in the Polish power system played the role of the operator of the transmission network.

The length of electrical lines on particular voltage levels and the total capacity of main transformers at the end of 2005 were as follows:

- high voltage lines-45,500 km,
- medium voltage lines-233,800 km,
- low voltage lines-286,900 km,
- main transformers-total capacity of 126,629 MVA.

The distribution sub-sector covers 14 distribution enterprises (including the privatized Górnośląski Zakład Energetyczny S.A. with the share of foreign capital amounting to 75%, and STOEN S.A., in which the share of foreign capital amounts to 98%) holding the concessions from the President of the Energy Regulatory Office for the distribution, transmission and turnover of electricity. They are responsible for the distribution of electricity through 110 kV lines and medium voltage network, supplying energy to final consumers and commercial turnover of energy. Moreover, ca 200 other companies have concessions for the turnover of electrical energy. Distribution companies own most of 110 kV lines and the entire low and medium voltage distribution network.

3. Polish energy policy on renewable energy sources

The Polish Council of Ministers accepted on 4 January 2005, the National Energy Policy—Energy Policy of Poland until 2025. This document describes directions of energy sector development, including renewables.

The most important objectives of Poland's energy policy include:

- ensuring energy security of the country,
- increasing the competitiveness of the economy and its energy efficiency,
- protecting the environment from the negative effects of energy-related activities, concerning generation, transmission, and distribution of energy and fuels [11].

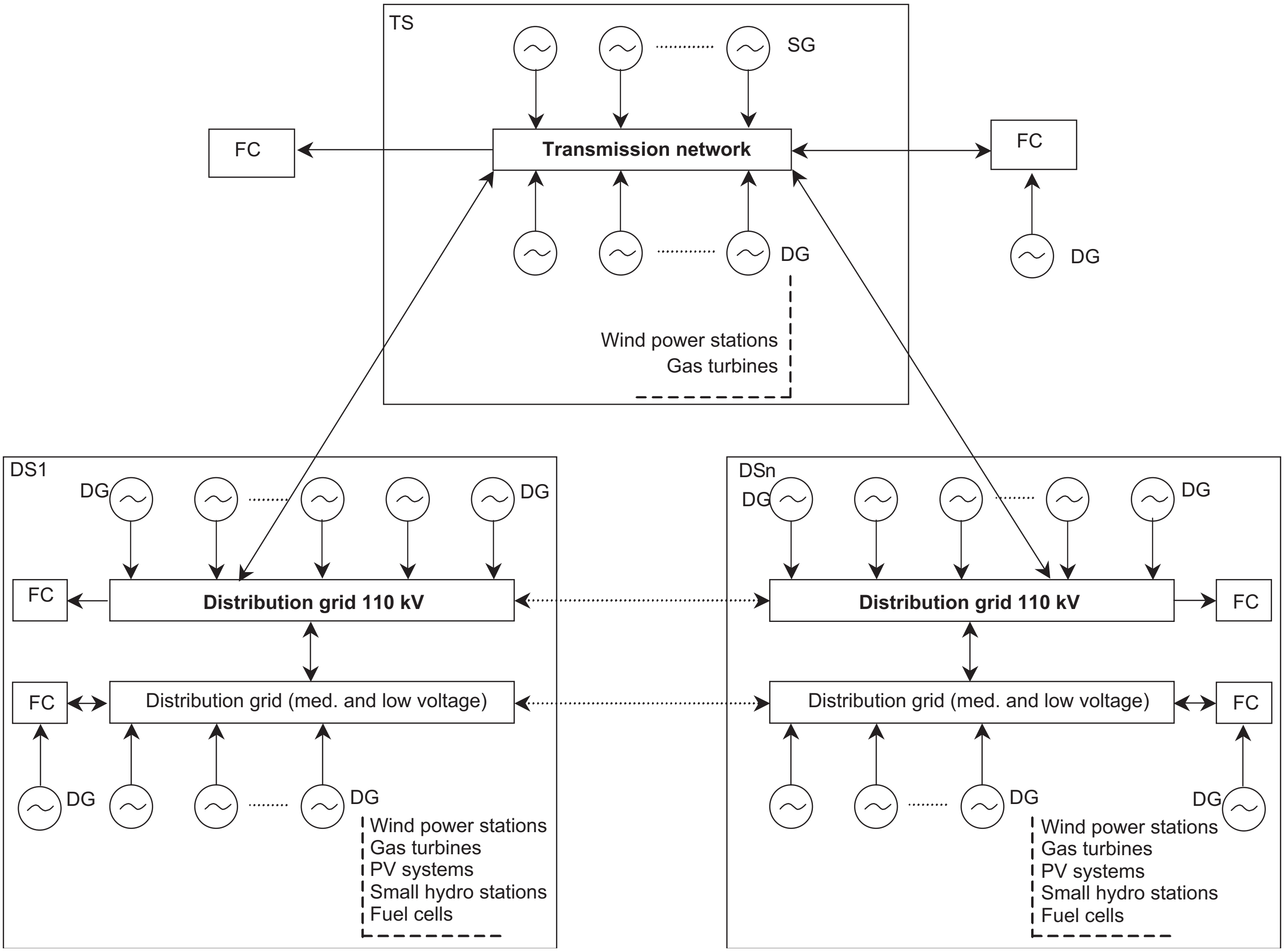

Fig. 1. Distributed generation in Polish electric power system: TS-transmission system, DS-distribution system, SG-system (centralized) generation, DG-distributed generation, FC-final consumer.

One of the components contributing to the realization of these priorities is an increase in the use of RES, which will result in a decrease of the country's dependence on imported energy carriers. In addition, air pollution is reduced by avoiding pollutants emitted from conventional energy sources.

According to the Energy Policy until 2025 the rational use of RES is one of the important components of the country's sustainable development. The degree of use of RES depends on their availability and their processing technologies. The document Energy Policy of Poland until 2025 puts forward biomass (energy crops; firewood; wastes from agriculture, industry and forestry; biogas), wind power and hydropower as the sources offering the greatest potential for use in Poland with the current energy prices and conditions for state aid. Due to its low cost-effectiveness for electricity generation, solar energy technology can play an important role mainly in heat generation, as well in isolated electric power grids, which are not connected to the national grid. Next in line is the use of geothermal energy sources. However, due to lack of experience of electricity generation from such sources, implementation of geothermal prototype projects in the nearest future is foreseen in local CHP plants.

The strategic objective of the State's policy as regards RES is the promotion of their development and attaining a 7.5% share of renewable energy in the primary energy balance in 2010. This should be carried out in such a way as to ensure the utilization of individual kinds of RES favors competition promoting most economically effective sources and not to lead to excessive increase in energy cost for consumers. This should be the fundamental principle for development of the use of RES [12].

The share of electricity from RES in the total gross consumption of electricity in the country should attain 7.5% in 2010. This is in line with the indicative quantitative objective stipulated for Poland in Directive 2001/77/EC on the promotion of electricity produced from RES [13].

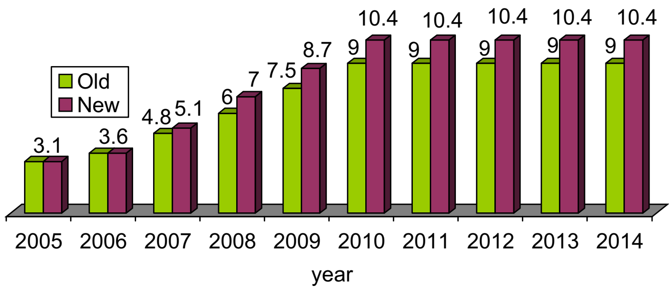

Fig. 2. The scope of RES obligation: "old"—from year 2005, "new"—from November 2006.

In order to ensure the proper position of RES within the power industry, Energy Policy until 2025 underlines actions which should be executed in the following directions.

- Maintaining the stable support mechanisms for the use of renewable energy sources.
- The use of biomass in electricity and heat generation.
- Intensification of use of small-scale hydro power.
- Increased use of wind power.
- Increase of share of bio-components in the liquid fuel market.
- Development of industry for renewable energy generation.

A core of the legislative activities having the aim of supporting the development of renewable energy is the act of the April 10 1997—the Energy Law [3]. According to the provisions of this law, energy companies selling electricity to final consumers have to obtain and submit the certificates of origin for cancellation to the President of the Energy Regulatory Authority, or have to pay a substitution fee.

The scope of obligation, defined in the regulation determines % share of electricity produced from RES sold to final consumer and is shown in Fig. 2. Fig. 2 also presents changes in obligation determined by the decision of Ministry of Economy from November 2006 [4]. This obligation determines attaining the national goal of 7.5% of electricity from RES in the total gross electricity consumption in 2010 [5].

The substitution fee is defined as $O_z = 240 \times (E_0 - E_u)$ zloties,[1] where $(E_0 - E_u)$ is the extent to which obligation is not fulfilled. Funds from substitution fee constitute a revenue of the National Fund for Environmental Protection and Water Management and support only RES development. In fact, the substitution fee describes the maximum price level of certificates of origin.

The Energy Law Act also describes a second obligation imposed on distribution companies—the obligation of purchase of the whole amount of electricity generated from RES at average market price of "conventional electricity". Average market price is announced by the President of the Energy Regulatory Authority. So finally investors and producers of electricity from RES have two kinds of incomes:

- from that guaranteed by the law of sales of electricity at the market price, and
- from sales of property rights from the certificates of origin.

The Minister responsible for economy systematically checks the functioning of the Energy Law in the area of use of energy from RES; thereby ensuring effectiveness of the regulations which obliges purchase of electricity produced from these sources. What results in introducing consecutive amendments act—Energy Law and modifications in the ordinance of the Minister responsible for economy concerning obligatory purchase energy from renewable energy sources. A valuation of the functioning of the Energy Law is carried out inter alia based on the President of Energy Regulatory Authority's annual report on activity, current analysis of functioning of Energy Law regulations and executive ordinance suitable for incoming correspondence from producers of electricity from RES, and also during many meetings about the topic of RES. Details of obligations are described in the ordinance of the Ministry of Economy dated December 19 2005 regarding the detailed scope of obligations to obtain and submit the certificates of origin for cancellation, payment of the substitute fee and purchase of electrical energy and heat generated using renewable energy sources, being the realization of delegated legislation included in the act—Energy Law—which target is the introduction and development of a system for a support mechanism utilizing the market mechanism and also settle its rules in a way conductive to optimum development and competition.

4. Current status and perspectives of RES in Poland

Table 1 and Fig. 3 show the installed capacity for different RES technologies for the period 2002–2006 [14].

The share of electricity from RES in the gross electricity consumption in Poland increased from approx. 1.68% in 2000 to approx. 2.8% in 2006. Table 2 shows the quantity of electricity generated from RES and its share in the gross electricity consumption for the period 2000–2006.

The share of electricity generation from RES in Poland's total electricity consumption increased from 2000, however, not steadily during the 6 years. In 2003 the RES share was lower than that during the other years, in spite of the increased installed capacity. The reason was hydrological conditions causing a decrease in the electricity generation in hydropower plants. Currently hydropower is the major renewable source of electricity. The drop in 2003

[1] Polish currency unit.

Table 1
Installed capacity in RES power plants 2002–2006

Installed capacity (MW)	2002	2003	2004	2005	2006	Number of installations in 2006
Biogas	15.0	18.0	22.0	31.9	36.8	74
Biomass	1.1	16.6	51.9	189.8	238.8	6
Wind	59.0	60.0	65.0	138.0	152.6	104
Hydropower	840.0	873.0	881.0	1002.5	1081.5	684
Co-firing	–	–	–	–	–	18[a]
Total	915.1	967.6	1019.9	1368.2	1443.7	886

[a]These power plants are using 2-20% of renewable energy sources, in many cases biomass.

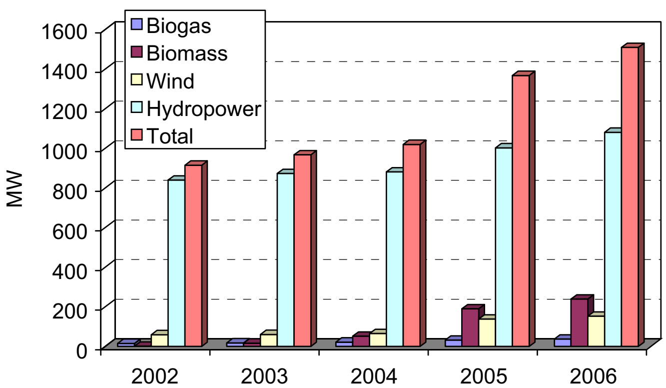

Fig. 3. Installed capacity in RES power plants 2002–2006.

was followed in 2004 by an increase in the electricity generation in all plants using RES. In addition, the use of co-combustion (co-firing) of biomass and fossil fuels increased in commercial and industrial power plants.

Table 3 shows the quantity of electricity generated from different RES for the period 2000–2006.

Percentage share of electricity generated from different RES technologies is illustrated in Fig. 4.

The pattern of the electricity generation from RES 2000–2006 shows that hydropower has the largest share. Next in line, biomass, wind and biogas also play important roles. An analysis of figures on electricity generation from RES during 2000–2005 shows a dynamic development of the biomass technology—including biogas and co-firing of biomass with fossil fuels—and wind power, as well as hydropower in small-scale hydropower plants with capacity up to 5 MW.

In the Accession Treaty, Poland adopted an indicative target stating that 7.5% of the country's total gross electricity consumption should come from RES by 2010. Therefore, activities for promotion of increased use of renewable energy, with a view to achieving this target, are given priorities. According to the Ministry of Economy, due to economical and environmental issues in Poland the most important perspectives to growth are three kinds of RES technology—biomass, wind and hydropower, especially from small hydropower plants.

Fig. 5 shows the foreseen structure of RES in 2010 in Poland [15].

5. Technologies of RES and their implementation in Poland

5.1. Hydropower

Hydropower was already used in pre-industrial times for driving mills, sawmills, and hammer works. Both the kinetic energy and the potential energy from flowing water can be converted into mechanical power by a turbine wheel, which in turn can drive machines or generators. Hydropower is a mature technology which, worldwide, generates the second largest share of energy from renewable sources, after the traditional use of biomass. 17% of the electricity consumed in the world today is generated by hydroelectric power stations [6].

There are different types of turbines with different areas of application, depending on the flow rate and the head (pressure) of the water. The Kaplan water turbine functions like a marine screw propeller on a vertically suspended axle. Both runner blades and distributor are adjustable and can be optimally adapted to the flow conditions. The water flows along the axis through the runner. A variation of the Kaplan water turbine is the tubular turbine in which the axis of rotation is horizontal. Kaplan and tubular turbines are used for low heads and high flow rates. The conventional Francis water turbine is one of the oldest types of turbines and is still mainly being used in small-scale hydropower plants. Typical for the Francis turbine is the spiral-shaped housing. It is used for small heads and medium flow rates. Only the distributor is adjustable with this type of turbine. The water flows radially into the runner and exits along the axis of rotation. Special forms of the Francis turbine can also be used for large heads and high flow rates. The Pelton turbine is suitable for large heads and low flow rates. After passing through a penstock, the water is injected at a high rate through the nozzles onto the paddles of the turbine. Direct flow turbines are used in the case of low head and low flow rates, with a low rate of power production. The water passes through the running wheel at a tangent.

Of all the sources of renewable energy, hydropower provides the largest contribution to the generation of

Table 2
Share of electricity from RES in Poland's gross electricity consumption

	2000	2001	2002	2003	2004	2005	2006
Electricity generation from RES (GWh)	2331	2782	2767	2250	2893	3761	4203
Gross electricity consumption (GWh)	138,810	138,886	137,057	141,463	144,831	146,221	150,873
Percentage electricity from RES	1.68	2.00	2.02	1.59	2.00	2.6	2.8

Table 3
Quantity of electricity generated from different RES 2004–2004 (GWh)

Type of RES	2000	2001	2002	2003	2004	2005	2006
Biogas	31	41	48	56	66	105	94
Biomass	190	402	379	398	604	1345	1821
Wind power	6	14	61	124	142	135	253
Hydropower	2105	2325	2279	1672	2081	2176	2035
Electricity generation from RES	2331	2782	2767	2250	2893	3761	4203

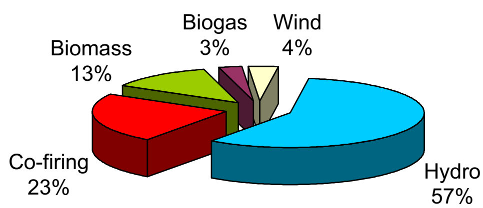

Fig. 4. Share of electricity generated using different RES technologies.

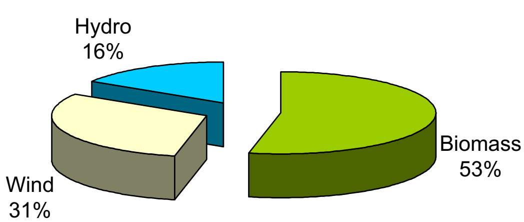

Fig. 5. Foreseen structure of RES in 2010.

electricity in Poland today. The installed capacity in the hydropower plants is growing steadily, particularly in small-scale plants. However, the electricity generation from RES in 2003 was lower than during the preceding years due to fact that the precipitation was low and unevenly distributed over the year. In 2004 the electricity generation in hydropower plants was 20% higher than in 2003.

Table 4 shows the installed capacity in hydropower plants for the period 2002–2006. Table 5 shows the quantity of generated electricity, and Fig. 6 is a graphical representation of the same data. Location of the largest hydro power plants in Poland is shown in Fig. 7.

Even though the existing potential for hydropower in Poland is not yet completely exploited, because of political decision, further expansion is only possible to a limited extent. Operating a hydropower station is always associated with a serious intrusion into ecological systems. Energy policy indicates development of hydropower only in small-scale power stations.

Table 4
Installed capacity in hydropower plants 2002–2006

Hydropower plants	2002	2003	2004	2005	2006
Installed capacity (MW)	840	873	881	1002	1081
in plants with capacity < 10 MW	210	236	243	n/a	n/a
in plants with capacity > 10 MW	630	637	638	n/a	n/a

Table 5
Generated electricity in hydropower plants 2000–2006

Hydropower plants	2000	2001	2002	2003	2004	2005	2006
Electricity generation (GWh)	2105	2325	2279	1672	2081	2176	2035
in plants with capacity < 5 MW	596	606	701	547	638	642	656
in plants with capacity > 5 MW	1509	1719	1578	1125	1443	1534	1379

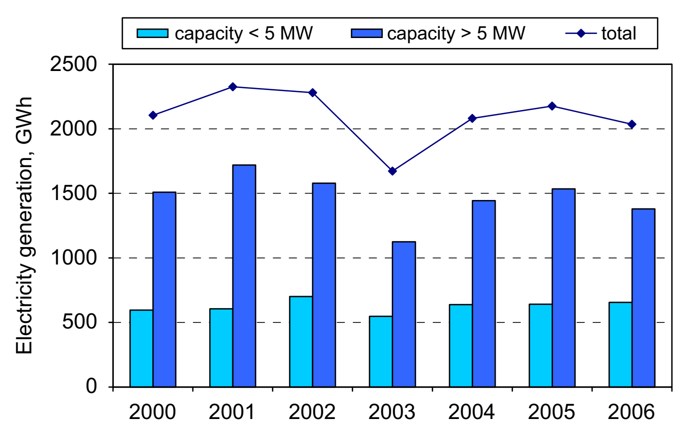

Fig. 6. Electricity generation in hydropower plants in Poland 2000–2006.

5.2. Wind power

Wind power has been used by man from time immemorial. Before the steam engine was invented, trade across the oceans was only possible by means of sailing

Fig. 7. The largest hydropower plants location in Poland.

vessels. Windmills ground grain and drove water pumps for irrigation and drainage purposes. Nowadays wind power is using for production of electricity.

As we know, energy production in wind turbines depends mainly on wind speed in a place in which wind power plant is located. This dependency is called "power curve", an example of which is shown in Fig. 8 [7,8]. Depending on the wind velocity, it is possible to differentiate between 4 phases of operation. At very low wind speed, the wind energy is not sufficient to overcome the system's moments of friction and inertia, and the rotors remain stationary. Starting at a certain wind velocity—about 3 m/s depending on the design—the wind turbine will turn. In this phase, the power output increases as a function of the wind speed to the power of 3, i.e. twice the wind velocity produces 8 times the electrical power. If the wind velocity increases further, then the maximum capacity of the generator will be approached, and the energy generation has also reached its maximum. The surplus energy from a further increase in wind velocity must be bypassed. The maximum power of the system is thus determined by the flow over the rotor area, and does not depend on the number of rotor blades. During a gale-wind speed of about 24–26 m/s, the mechanical load on the rotors is too high. Pitch-controlled turbines and active-stall systems are then taken off the grid and the entire rotor is

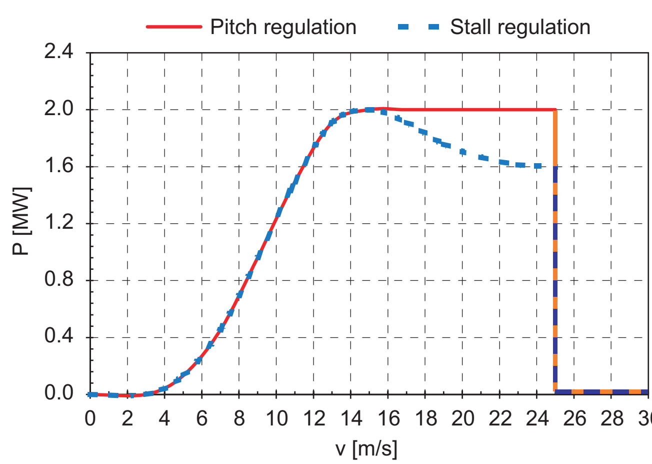

Fig. 8. An example of 2 MW wind turbine power curve.

turned out of the wind to protect the overall turbine structure. The rotor spins with no load. Stall-regulated systems are halted aerodynamically with blade-tip brakes.

There are 3 different concepts for controlling power output. In the case of stall-controlled systems, the rigidly fixed blades and the constant rotor speed stall above a certain wind velocity. In this case, the rotor performance remains almost constant even if the wind velocity increases

further. The straightforward design of stall-controlled turbines resulted in its widespread installation in the early years of wind energy use. In the megawatt range, the blade-controlled design of turbines (also referred to as pitch control) dominates. In these systems the rotor blades can rotate about their longitudinal axis and adjust to the relative wind conditions. As a result, the power output of the rotor can remain constant after the rated power is reached. Although pitch-controlled turbines are more complicated to construct, they achieve a better yield and the thrust of the rotor on the tower and foundations is lower than for stall-regulated turbines. The active stall regulation is a compromise between pitch and stall. At low wind speeds, the blades are pitched like in a pitch-controlled wind turbine in order to achieve a higher efficiency. When the wind turbine reaches the rated capacity, the active stall-regulated turbine will pitch its blades in the opposite direction and stall.

Nearly all the wind turbines installed today have 3 rotor blades, since the mechanical loads are easier to control with this design and because three-blade rotors are considered by most people as optically more harmonious than single or two-blade rotors. The blades themselves are usually made of glass-reinforced plastics and are more than 50 m long for large turbines.

Depending on their rated capacity, modern large-size rotors turn at 10–30 revolutions/min. Since control and constancy of the power output are of major importance, particularly for large turbines, the number of turbines with a variable rotor speed has increased significantly in recent years. The operating point for the greatest efficiency can be maintained over a large wind-velocity range by matching the speed to the rotor aerodynamics. Gears are needed if the common 4-pole type of generator is used to transform the low rotor speed to the required generator speed of 1500 revolutions/min. The losses attributed to the gears are about 2% per stage and, additionally, the gears are themselves a source of noise emissions. Gearless systems do not have these problems, however, they require specially manufactured multipole generators. Generators can be realized with synchronous or asynchronous designs. The advantages of the asynchronous generator are in the relatively simple control system construction and the possibility for direct connection to the grid. However, it is relatively inflexible in adapting to the grid and does not allow continuous regulation of the rotor speed. A variant of the simple asynchronous principle is the double-feed generator, where the current from the rotor in the asynchronous generator is regulated by an inverter. This principle makes it possible to regulate the speed over a wide range. A comparable rotation-speed variability is given by the synchronous generator in combination with an inverter. In a stand-alone operation, the synchronous generator is able to establish and stabilize its own electrical grid.

The towers of the largest wind turbines today are more than 120 m high, so that together with the rotor blades the wind turbines reach a height of up to 170 m. As a rule: the higher the tower, the less interference from air turbulence caused by ground roughness, and the mean wind velocities are higher. The towers are generally realized as steel-jacketed constructions which least influence the surrounding countryside due to their slim design. Positive experiences have been made with painting the base of the tower in the predominant color of the surroundings, and the rest, higher up, with a non-reflecting color (light gray). Over the last 20 years, the technical development of wind turbines concentrated mainly on realizing ever larger constructions in order to optimally exploit those sites where the wind conditions are most favorable, thereby triggering a phase of rapid technical progress. While the average capacity of wind turbines installed in 1987 was less than 50 kW, it has since increased by a factor greater than 30 to 1.5 MW in 2003. It is difficult to predict today which capacity will represent the technical and economical optimum. The first wind turbine with a capacity of 4.5 MW was installed in 2002. The yield from such a system covers the electricity demand of about 5000 households. Development of wind mills is shown in Fig. 9 [16].

During 2001–2006 the generation of electricity in wind power plants increased by 250 GWh. In 2005 the wind power plants generated 136 GWh, which corresponded to 4.9% of the electricity generated from RES, and 0.1% of the country's gross electricity consumption. Analyses indicate a continued dynamic growth of wind power. In 2004–2005 installation of a series of wind farms started, and they will lead to an increase in the installed capacity. Table 6 and Fig. 10 show the quantity of generated electricity and the installed capacity in Polish wind power plants.

The Polish wind potential is comparable to the wind potential of the "world wind giant," Germany. It is also compares favorably with countries where a significant share of energy is obtained from wind, such as Denmark or Sweden. According to the Institute of Meteorology and Water Management about 30% of Polish territory have an average wind speed over 4 m/s. A preliminary estimate of the available resource is presented in Fig. 11. The map shows that the north of Poland particularly experiences high wind speeds for a significant fraction of the year. Location of the largest wind mills in Poland is shown in Fig. 12 [17].

5.3. Biomass and biogas

The oldest and simplest way of using energy is to burn the biomass. To assure complete combustion and low emissions, while taking into consideration the ash content, the fuel composition, and the shape and size of the fuel particles, different types of burning, which essentially differ in the type of fuel processing and the fuel feed method, were developed for the various plant sizes.

The use of biomass for generating electricity and heat is a particularly attractive form of energy conversion from the

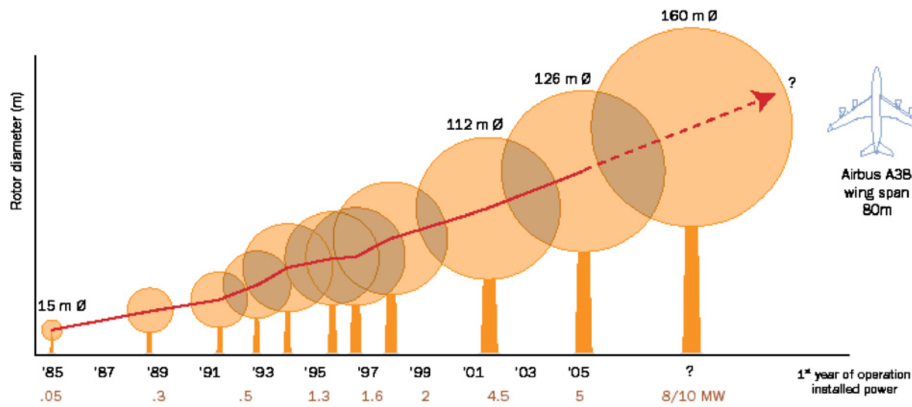

Fig. 9. Size growth of commercial wind turbine designs.

Table 6
Electricity generation and installed capacity in Polish wind power plants

	2000	2001	2002	2003	2004	2005	2006
Electricity generation (GWh)	6	14	61	124	142	135	253
Installed capacity (MW)	4	18	59	60	65	138	152

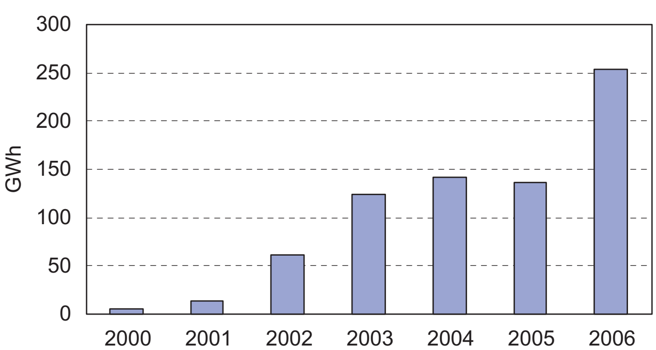

Fig. 10. Electricity generation in Polish wind power plants.

climate point of view. When growing, the biomass first removes the greenhouse gas CO_2 from the atmosphere and binds the carbon in the biomass. This carbon is later released into the atmosphere again, i.e. as a result of combustion or when the biomass is rotting. Therefore, when biomass is used for energy purposes, then only that CO_2 is released which was previously removed from the atmosphere when the plant was growing.

Included amongst the most important biogenous fuels are of course wood and leftover timber accumulating from forestry, in sawmills or as old timber. Fast-growing trees, e.g. poplars and willows, can be planted in so-called short-turnaround plantations and be harvested within a few years. Reed (miscanthus) is potentially a very high-yield regenerative raw material; however it requires high-quality fertile land and a good water supply. Residuary straw, as well as special grain plants such as e.g. the wheat-rye hybrid triticale, are also suitable for producing energy. Plants which contain sugar and starch, like corn and sugar beets, can be used for making bio-alcohol. Also included as biomass are those oil-containing plants, which, by pressing and subsequent processing, can be converted into liquid energy carriers. Organic residuals are also suitable energy sources. Liquid manure, bio-waste, sewage sludge, and municipal sewage and food leftovers can be converted into high-energy biogas. Biogas is also released from landfills. Location of biomass plantations in Poland is shown in Fig. 13.

The interest in producing electricity from biomass has increased considerably since adoption of the co-firing regulation in May 2004—biomass and conventional fuels, e.g. coal. Also regulations which support using of biomass from energy crops rapidly caused an increase in interest for connection agriculture and energy sector.

1821 GWh of electricity was produced from biomass in 2004. This was over 1500 GWh more than in 2000, i.e. an increase by 500%. For the next years, a continued growth of electricity generation from biomass is foreseen, including co-firing of biomass and other fuels. However it should be noted that forest biomass is primarily intended for use in the wood industry, the pulp and paper industry and the wood panel industry. In view of this, the use of biomass from energy crops, as well as from wastes and residues from agriculture and industrial agro-processing, is promoted through the introduction of a provision saying that such kinds of biomass should constitute a minimum percentage of the total quantity of biomass used in co-combustion processes. This minimum percentage will increase gradually over the coming years.

Table 7 and Fig. 14 show the quantity of electricity generation and the installed power in biomass power plants in Poland.

Also biogas is considered to be an attractive and relatively cheap energy source. In addition, disposal of biogas by combustion is absolutely necessary to protect the environment; in particular, to protect the atmosphere against emission of unburned methane contained in biogas. Biogas can be used in gas-driven electricity generators, gas boilers and CHP systems. A gradual growth of the use of biogas, particularly from landfills, has commenced.

Fig. 11. Wind potential of Poland; zones: I—very favorable, II—favorable, III—sufficient, IV—insufficient, V—bad.

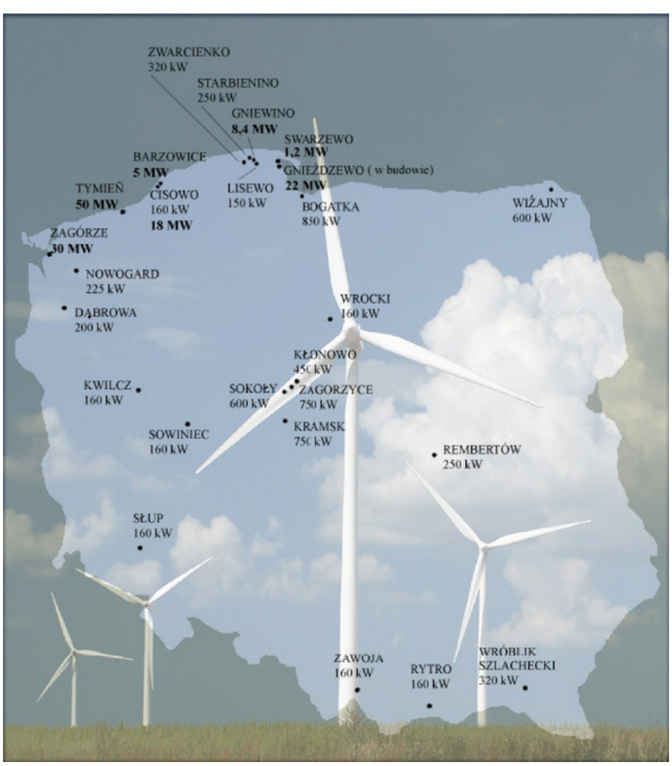

Fig. 12. Location of the largest wind power plants.

In 2003, plants using agricultural biogas, as well as biogas from municipal sewage works, began to be built. However, the installed capacity of those plants is still low. The electricity generation from biogas increased from 31 to 104.5 GWh during 2000–2005, i.e. by nearly 300%. Since biogas has a relatively great potential, a further increase is expected.

Table 8 shows the installed capacity of biogas power plants and the quantity of electricity generated.

A very promising alternative for burning is the gasification of biomass. Using gaseous biogenic fuels, it is possible to apply proven and efficient techniques like gas turbines and cogeneration units. The future use of biomass in fuel cells, which provide high yields of electricity even from small-power units, is possible with gasified wood.

5.4. Solar energy

Solar cells directly convert sunlight into electrical energy without any mechanical, thermal, or chemical intermediate steps [18]. At the core of all solar cells is a semi-conducting material, usually silicon. Solar cells utilize the photovoltaic effect; for certain arrangements of superimposed semiconductor layers, free positive and negative charges are

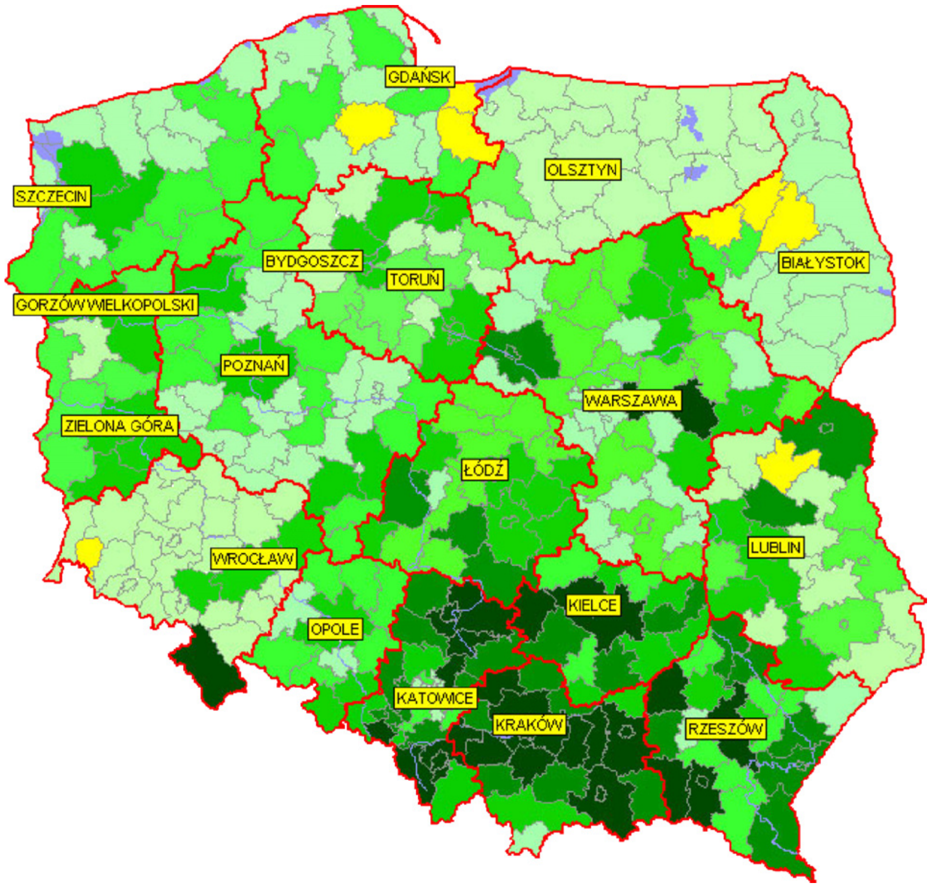

Fig. 13. Location of biomass plantations.

Table 7
Electricity generation and installed capacity in biomass power plants 2001–2006

Biomass	2000	2001	2002	2003	2004	2005	2006
Electricity generation (GWh)	190	402	379	398	604	1345	1821
Installed capacity (MW)	N/A	N/A	N/A	16.6	51.9	189.8	238.0[a]

[a]Without co-firing technology.

generated under the influence of light (photons). These charges can then be separated by an electrical field and flow as electrons through an electrical conductor. The direct current thus generated can be used for powering electrical devices or stored in batteries. It can also be transformed into alternating current and fed into the national grid.

In the meantime, many different kinds of semiconductor materials are available for making solar cells. However, silicon is still the most important element. Silicon is produced in 3 variations.

- Very pure mono-crystalline silicon is expensive due to its complicated manufacturing process, but it enables the highest conversion efficiencies.
- Poly-crystalline silicon is more simple and cheaper to produce. However, the lower purity of the material leads to a somewhat lower efficiency, which in turn requires larger areas and frames for the same electricity production.
- The thin-film cells from amorphous silicon are even cheaper to produce. Both the efficiency and the lifetime are, however, much lower than for crystalline cells, a fact which largely compensates the cost advantages.

Besides silicon there is a variety of other materials and combinations of material being developed and undergoing testing. Considerable cost reductions are expected especially in the field of thin film technology, where considerably less material is needed than for crystalline cells. Besides amorphous silicon, the most important materials for solar cells are e.g. gallium arsenide (GaAs), germanium (Ge), cadmium telluride (CdTe) and copper indium diselenide (CIS). A very promising concept for the future is that of the so-called tandem cell, in which several semiconductor materials are combined in such a way that a larger range of the irradiated sunlight spectrum can be converted. Laboratory-scale cells with a combination of gallium arsenide and gallium antimonide, measured under concentrated light, have achieved efficiencies that are significantly higher than those of the basic solar cell.

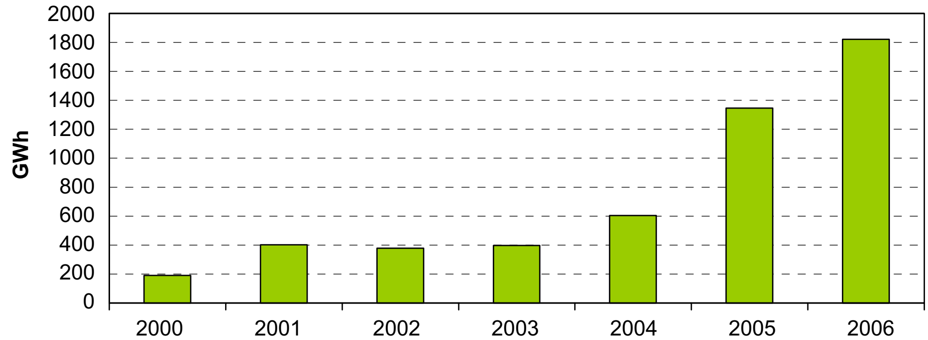

Fig. 14. Electricity generation from biomass in Poland.

Table 8
Electricity generation and installed capacity in biogas power plants in Poland 2002–2006

	2002	2003	2004	2005	2006
Electricity generation (GWh)	48.0	56.0	66.0	104.5	94.7
Landfill gas	48.0	45.0	50.0	N/A	N/A
Agricultural biogas	N/A	9.0	10.0	N/A	N/A
Biogas from municipal sewage plants	N/A	2.0	6.0	N/A	N/A
Installed capacity (MW)	15.0	18.0	22.0	33.4	36.8

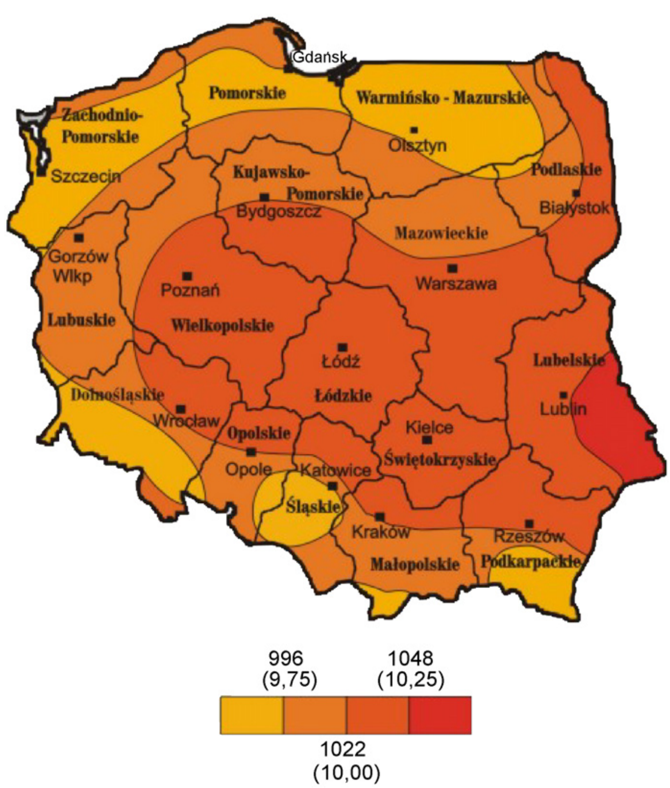

Fig. 15. Distribution of global solar radiation in Poland [kWh/m^2 per year (MJ/m^2 per year)].

Although there is less sunshine in Poland than in more southern countries, photovoltaic systems are also useful at our latitudes, since solar cells can also convert diffuse solar radiation into electrical energy. The annual average of solar radiation is higher in the south than in the north of Poland—see Fig. 15, amounting to between 990 and 1050 kWh of incident energy/m^2 each year.

A modern solar cell can convert, on average, one-tenth of this solar energy into electricity.

During recent years we could not only observe a drastic increase in demand for photovoltaic systems, but also a significant reduction in costs. The costs for a PV system now are about half of what they were in the early nineties. The investment in a roof-installed system on a house today costs about €6500/kW of installed capacity, while larger systems are somewhat cheaper at about €5000/kW. Whereas electricity from photovoltaic systems costs about €1.5/kWh in 1985, today the electricity generation costs in Central Europe are between €0.50/kWh for large grid-connected generators and €0.75/kWh for decentralized small-scale systems, depending on the particular application and technology.

Considerable cost reduction is expected in the future as well. It is assumed that present-day costs will be halved by the year 2010, especially as a result of significantly increased series-production volumes. Improved materials yield—today a large proportion of the semiconductor material is lost by sawing the wafers and during other processing steps—and higher efficiencies will help to lower the costs associated with this innovative source of electricity.

The installed capacity of PV systems by 2003 was around 120 kW, and in 2004 around 234 kW in Poland. Of this capacity around 165 kW was not connected to the grid. In 2005 there was installed over 300 kW but all of them were not connected to the grid. Due to this fact statistical data are not detailed.

Growth of the installed capacity of solar cells has been observed, but due to the high investment costs wide use is not foreseen except for specific purposes.

6. Conclusions

For our energy supply to become sustainable, it needs to satisfy a large number of requirements: climate compatibility, sparing use of resources, low risks, social equity and public acceptance. At the same time it should also give

a fresh boost to innovation and help create jobs with a future. Numerous worldwide and regional studies indicate that RES are capable of meeting these requirements. Relevant global and national scenarios for the future indicate substantial growth in the share of energy supplies that will be accounted for by RES in the decades ahead. It is becoming increasingly clear that faster expansion of renewable energy systems is a necessary requirement for a sustainable energy future.

Looking at it today, a completely objective consideration and weighting between overall recognition of endangering the global climate, the expected tendency for fossil fuels to become scarce and costly, the diverging attitudes towards the risks associated with nuclear energy, and the economic and social damage caused by the extreme inequality in access to energy does not appear possible. The previous discussion does, however, allow certain basic conclusions to be drawn: a future energy supply should not be based on fossil energy carriers. Instead, a system needs to be established which is in accordance with the guidelines for sustainable energy supply, or which at least allows us to move towards the sustainability targets we aim for. There are 3 basic strategic components supporting the restructuring of the energy supply system, which are referred to as "efficiency", "consistency", and "sufficiency": None of these components alone can ensure success—they are complementary and only through their close interaction can sustainability goals be met. A significant reduction in energy consumption is required to allow renewable energy to provide a reasonable share of energy demand in a cost-effective way. Only an energy-conscious way of life will pave the way for the success of energy-efficient technologies. On the other hand, each saved unit of energy makes saving any additional unit of energy more difficult. As we do not envisage a "zero-energy society", the sustainable use of renewable energies is necessary. A more efficient use of energy sources and the substitution of finite resources by renewables are 2 sides of the same coin. In a parallel development, the values in society must be reoriented away from the constantly growing consumption of goods to a more qualitative satisfaction of consumer needs and a strengthened sensitivity towards the environment. Such a change does, however, need a long time. In particular, the ongoing globalization of all kinds of activities, including consumer behavior and the strong focus on short-term economic successes, hinders such re-orientation. A large variety of "social innovations" is therefore required before being aware of how we treat natural resources becomes a matter of course.

Renewable energy is characterized by a diversity of resources and technologies for the enormous power range from a few watts to hundreds of megawatts. Renewable energy can be adapted to any kind of energy service and be closely inter-linked with conventional modern energy technologies to ensure security of supply at all times and at any location. Renewable energy technologies are compatible with modern supply systems which increasingly rely e.g. on DG and network integration, like in "virtual" power plants and district-heat supply systems.

There are currently 5 main support mechanisms of electricity from RES in the EU—investment subsides, fixed price mechanisms, fixed premium mechanisms, quota system based on auctions or tradable green certificates. Poland decided to choose the quota system based on tradable green certificates system. It is expected that together with other, additional supports, such as investment subsidies, Poland will achieve its ambitious target in 2010 and fulfill the sustainable development standards.

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